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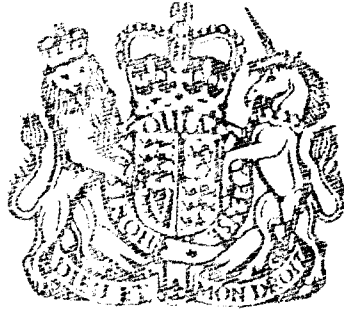
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Propellants, Explosives
and Rocket Motor
Establishment,
Westcott, Aylesbury, Bucks

Memorandum 111

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The use of an Arc Image Furnace for
Solid Propellant Ignition Studies
an Undergraduate Student Report

J B DAWES

May 1980

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PROPELLANTS, EXPLOSIVES AND ROCKET MOTOR ESTABLISHMENT
WESTCOTT

Memorandum No. 111 *

Approved March 1980

(6) THE USE OF AN ARC IMAGE FURNACE FOR
SOLID PROPELLANT IGNITION STUDIES,
AN UNDERGRADUATE STUDENT REPORT,

by

(10) Jacqueline Bernadette/Dawes

(14) PERME-MEMO-112

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SUMMARY

An arc image furnace has been used to test the ignition delay of rocket propellant under varying conditions of heat flux and pressure.

* This Memorandum has been prepared during an industrial training period from August 1979 to January 1980 for Sunderland polytechnic

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CONTENTS

	Page
1 AIM	1
2 INTRODUCTION	1
3 DESCRIPTION OF APPARATUS	2
4 EXPERIMENTAL PROCEDURE	5
5 TREATMENT OF RESULTS	6
6 RESULTS	8
6.1 Propellant 'X' - Composite propellant	8
6.2 Double Base (cordite) propellant	9
7 DISCUSSION	10
7.1 'X' propellant	10
7.2 DoubleBase Propellant	11
8 REFERENCES	12
9 Figures 1 to 7	

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1 AIM

The aim of this project is to measure the ignition delay of several different types of solid propellant under selected conditions of heat flux and pressure and to compare the results thus obtained with ignition data obtained by other members of the Section by other methods.

2 INTRODUCTION

The arc image furnace is a laboratory device which may be used to ignite rocket propellant, simulating the conditions of overall heat flux and pressure levels obtained in the rocket motor¹. Ignition in a motor is usually initiated by a pyrotechnic device which produces a heating effect mainly by conduction of heat by hot particles impinging on the propellant surface and convective heating from the hot gases flowing over the surface. There is only a small proportion of the heat transferred by radiation from the igniter products. In the arc image furnace, however, radiant heat is the means used for igniting the propellant. Thus it is not an absolute test of ignition delay, but it gives an indication of the delays which may be expected from a solid propellant.

There are advantages and disadvantages in using the arc image furnace for this purpose. One of the disadvantages, as stated previously, is that the method used to ignite the propellant is not the same as that in the rocket motor itself. Evidence, however, suggests that the rate of ignition is dependent only on the rate and total quantity of heat transfer, rather than the type of heat transfer. Another disadvantage is that most propellants require a coating on their surface in order to increase their absorptivity when using the arc image furnace. This ensures that the difference in reflectivities and transparencies need not be taken into account when calculating the relative ignitability of the propellants. This coating, however, may be thought to affect the ignition delay by either physical or chemical means, i.e. forming a barrier or catalysing the propellant. It was found that zirconium carbide was the best substance for coating²; it produces the least interference with the propellant and has a high absorptivity. Depending on the propellant type, the zirconium carbide may either be merely brushed on, or mixed with acetone and applied. Care must be taken to avoid brush marks which could lead to three-dimensional heat transfer. The advantages of the arc image are that the energy is supplied external to the sample environment and the energy level is reproducible. Also, the reaction of the sample to the rate of supply of the radiant energy (which may be attenuated by inserting wire gauzes in the system) may be easily studied.

The ignition of the propellant is categorised "Go" or "No Go". A "Go" may be said to have occurred when complete burning of the propellant has occurred. A "No Go" may be said to have occurred when non-ignition, or incomplete ignition has

occurred, since ignition may sometimes be instigated but not completed.

3 DESCRIPTION OF APPARATUS

The arc image furnace consists of two rear-silvered ellipsoidal mirrors which are situated at twice the distance of the secondary foci apart (i.e. the two secondary foci coincide) and along the same optical axis (see Fig. 1).

At the primary focus is a xenon lamp which has an internal pressure of five atmospheres when not in use - when in use the pressure is considerably higher. The lamp is a commercial 4 KW Wotan lamp³. It consists of solid tungsten electrodes which are situated a few millimetres apart in an atmosphere of pure xenon gas and contained in a quartz envelope. Since the arc fills only the few millimetres between the electrodes, it provides a concentrated source of radiant energy at low voltage and high current. For safety reasons, the lamp is confined in a housing which would be able to withstand the high pressure explosion of the lamp, should this occur. A fan is installed in order to keep the lamp cool thereby reducing explosion risks. If for any reason the fan should fail, then a microswitch would be activated causing immediate shut down of the lamp. Other fans are installed; the first removes ozone, where ozone is produced in the lamp housing, the second removes vapours from the ignited propellant.

The power supply for the lamp is derived from a transformer-rectifier unit which operates from three phase mains. There is a starter unit supplied with the lamp which provides the initial ionization requirements, a discharge of 2 MHz at 45 KV.

In order to minimise errors, the lamp must be allowed to reach a steady state condition before testing begins, and also the mirrors must reach a thermal equilibrium. Failure of the lamp may be caused by a build up of tungsten from the electrodes on the quartz envelope. If this is not detected then the concentration of tungsten would cause an increase in temperature, thereby an increase in pressure, resulting in lamp explosion. The lamp must thus be periodically examined and a substantial deposit of tungsten entails the replacement of the lamp.

The primary focus of the second mirror is the test point. Here, initially, a Gardon Gauge radiometer^{4,5} is placed in order to measure the incident heat flux. When the test is being performed the radiometer is replaced by the "bomb" containing the propellant sample.

The radiometer is produced by Hy-Cal Engineering^{6,7} and is in effect a thermocouple whose cold junction is maintained by a water flow rate of 60 gallons/hour. The thermocouple is manufactured in copper and constantan. The constantan is in the form of a thin circular foil with a specially blackened surface which has an

absorptivity of 0.89. Around the circumference there is a block of copper which is a water cooled heat sink at constant temperature. The centre of the foil to which a thin copper wire is attached attains a higher temperature than other parts of the foil causing a radial heat flow to the copper block. A differential thermocouple is produced between the centre of the foil and the copper block. The electrical signal produced is directly proportional to the flux absorbed by the foil. The flux may thus be measured on a digital voltmeter. There is a calibration graph supplied by the radiometer manufacturers to enable direct conversion of the flux level. As this is supplied in either $\text{cal/cm}^2 \text{ sec}$ or $\text{Btu/ft}^2 \text{ sec}$ there is a further calibration required to enable the value to be stated in MW/m^2 . These factors are $1 \text{ cal/cm}^2 \text{ sec} = 0.041868 \text{ MW/m}^2$ and $1 \text{ Btu/ft}^2 \text{ sec} = 0.011353 \text{ MW/m}^2$. The radiometer is calibrated against an absolute standard by the manufacturers.

The stanchion on which the radiometer or "bomb" is mounted is controlled by a three-axis lathe bed cross arm. This enables the focus of the mirror to be accurately pinpointed by moving it on all three planes until the maximum mV reading is obtained in each plane. This is then the primary focus of the second mirror. The radiometer is offset from the maximum along the optical axis in order that a reproducible flux can be obtained for the loaded "bomb".

The propellant is held in a "bomb" which consists of two basic parts shown diagrammatically in Fig. 2. The first is a quartz window which is 15 mm thick and must be able to withstand a pressure of 200 psi (1.38 MN/m^2). The second part is a container for the propellant which positions the propellant at exactly the same position as that at which the radiometer was situated so that the propellant receives the same flux as that measured by the radiometer. We must, however, take account of the fact that the blackened surface of the radiometer does not have an absorptivity of one. This must be corrected since the absorptivity as stated previously is 0.89. In front of the propellant sample there is a perspex disc 2 mm thick which stops damage to the quartz by the propellant flame when ignited.

At the joint secondary focus is situated a fast rotating disc which is one of the three discs which constitute the shutter system. They rotate in a constant speed ratio of 400:20:1, i.e. each consecutive disc rotates at twenty times the speed of the previous one. The slowest and the next disc each have a circular hole near the periphery which is 1.25 inches in diameter. The fastest disc has a curved hole 6 inches long by 2 inches wide. There are obviously twenty positions in which the three discs align. They only pass light, however, when the discs are aligned along the optical axis of the system.

The speed of rotation of the discs is controlled by a 0.5 horsepower motor through a gear housing. The speed of the fastest rotating disc is noted on a

tachometer and is related to the exposure time of the propellant from the geometry of the system⁸:-

$$\text{Disc speed (in rpm)} = \frac{14400}{399 \pi p_t} \text{ where } p_t \text{ is the pulse time in ms.}$$

The pulse shape thus obtained is shown in Fig. 3. The pulse time (exposure time) is defined as the time for which the flux is greater than $0.5 I_{\max}$ where I_{\max} is the intensity of the beam when the shutter is fully open.

Between the first mirror and the secondary focus, gauzes are situated which are made of steel or copper. These control the level of radiation which is allowed to fall on the radiometer or propellant. These attenuators produce only a small interference pattern and do not become overheated. In fact, the attenuators have no effect on the shape of the flux distribution.

In order to check the exposure time of the propellant, a timer is incorporated into the system. This is designed so that it will only register the duration of the time for which the radiation is greater than $0.5 I_{\max}$. Fig. 4 shows a schematic diagram of the circuit.

A photo-transistor is situated on the optical axis of the mirrors, mid-way between the second mirror and the secondary focus with the sensing surface facing towards the secondary focus. The optical radiation may be sensed by this. To prevent the photo-transistor going into saturation at maximum intensity of radiation, the signal must be attenuated. This was done by filling the light guide with silicone grease. In effect, the signal from the photo-transistor is linearly dependent upon the incident flux. When, at the start of the test, the shutter is fully open then the variable amplifier is adjusted so that the Schmitt trigger⁹ receives an input of 3.6 V. Thus, when the shutter is half open 1.8 V will be input to the Schmitt trigger which will start the timer. The trigger is switched off when less than 1.8 V is passed to the Schmitt trigger. The timer then registers the result of the pulse time as defined above. The timer may be tested by pressing the switch along side the scale. This should read as a row of eights if it is working correctly.

There are many safety microswitches incorporated in the equipment to protect the operator. First, if the cover is off the lamp house the arc may not be struck. Second, if the fan cooling the lamp should fail then the lamp is automatically switched off. Third, the dowser (which is situated between the lamp housing and the rest of the equipment) has a microswitch such that if the panel in front of the "bomb" or radiometer is omitted, and the dowser is opened, the lamp will

extinguish. Finally, a microswitch is incorporated behind the panel referred to above, such that any attempt to remove the panel when the dowser is raised causes the lamp to extinguish.

The gas used to pressurise the "bomb" is nitrogen. Originally supplied in single cylinders which soon needed replacing, this system was modified so that an external supply from a "bank" of cylinders at higher pressure was then available. The test pressure was limited to 200 psi (1.38 MN/m^2) by the "bomb" which is only designed to withstand this working pressure, although in fact it has been pressure tested to 250 psi (1.725 MN/m^2). It is not advisable to allow these higher pressures to remain for extreme lengths of time.

Also concerned with the nitrogen supply is the method of transferring the nitrogen from the supply to the "bomb". Originally a nylon pipe joined the reservoir tank (which served as a surge tank to limit the pressure rise on ignition) to the "bomb" when in test. Unfortunately, the connectors occasionally failed thereby releasing gas and reducing the pressure. The nylon tubing was replaced by a stainless steel pipe. It was coiled beneath the arc image furnace to enable movement of the pipe in order to attach the "bomb" in position. These pipes must be cleaned periodically since the propellant gases pass into the tube when ignition is achieved.

For reproducible ignition it is necessary to have a smooth propellant surface. In order to obtain this for certain propellants which are pre-cut to approximately the correct size, a simplified microtome device was designed (see Fig. 5). Here a brass container may be adjusted to the required length of the propellant. The surface of the propellant may then be cut using a sharp knife. This is not the case for all propellants. Certain plastic propellants are merely pushed into the sample holder and cut off, when in position, to the required length. Others are supplied in strips where it is not only the length but also the diameter of the propellant which must be adjusted. Here a tube of certain bore size is pressed onto the propellant, thus cutting out a circle of the propellant of the required size.

4 EXPERIMENTAL PROCEDURE

When starting the furnace it is important to ensure that a flowrate of 60 gallons/hour of water is being passed round the radiometer. Initially the shutters are aligned so that light may pass, the dowser is raised, the necessary gauzes to attenuate to the required flux are positioned, and the radiometer is held in the lathe cross arm stanchion. The arc is then struck and the lamp is left for ten minutes in order that thermal equilibrium may be established between the mirrors.

After ten minutes the radiometer is moved in three planes using the lathe stanchion in order that the maximum flux is obtained. This is registered on a

digital voltmeter. When the maximum flux position is found the radiometer is moved off the peak so that a reproducible flux level may be obtained over a series of tests since variations in the AC supply lead to variations in the peak flux obtained. This off-setting must occur along the optical axis away from the second mirror. The Schmitt trigger level is then set at 3.6 V. The dowser is then shut and the panel taken off the front of the radiometer/"bomb" housing. The radiometer is then replaced by the loaded "bomb", the nitrogen line attached and the panel is then placed back and securely fastened. The transducer which is calibrated to measure the pressure must then be zeroed. After this the required pressure may be applied, and the discs set into rotation to give the required exposure time. When the pressure is set and the discs almost aligned along the optical axis, then the dowser is lifted and after exposure has occurred the time is displayed on the digital timer. A rise in pressure indicates a "Go"; a steady pressure indicates a "No Go". The pressure must now be released. The dowser is then lowered, the "bomb" removed and replaced by the radiometer. The flux level is checked and any adjustments necessary are made and the procedure is repeated.

There is provision for use of a chart recorder to register a "Go"/"No Go" but the technique of using a digital voltmeter to indicate the pressure was preferred. This enabled a more accurate measurement of the pressure to be made.

After a series of tests have been performed, and the machine switched off, the fans are left running for a period of approximately ten minutes in order to allow the lamp to cool down. This lessens the risk of lamp explosion.

5 TREATMENT OF RESULTS

Usually a series of fifteen combined "Go" and "No Go" tests are required in order to perform a Bruceton test. The object of the test is to find the mean ignition delay time and the Bruceton test provides a statistical measure of the mean. For the best results 7:8 is the best ratio of "Go" : "No Go" or vice versa.

A typical Bruceton test is as follows, where 0 represents a "No Go" and X represents a "Go".

Exposure time(τ) ms	Test Series															Calculations			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	i	n_i	in_i	i^2n_i
80													X			3	1	3	9
75								X				0		X		2	2	4	8
70			X				0		X		0				X	1	3	3	3
65		0		X		0				0						0	1	0	0
60	0				0												7	10	20

One must now choose the symbol which occurs less frequently - X in this case. In the column i a zero is entered in the row which corresponds to the lowest exposure time for which the less frequently occurring symbol appears. Consecutive numbers are placed in the column, corresponding to increasingly greater exposure times. In the n_i column is entered the number of less frequently occurring symbols which occur at that exposure time. The columns in_i and $i^2 n_i$ are then filled in as appropriate. The sums of n_i , in_i and $i^2 n_i$ are designated N, A, and B respectively. Using these values it is possible to estimate the mean ($\bar{\tau}$), the standard deviation (S), and the standard deviation of the mean ($S_{\bar{\tau}}$). The following formulae are utilised.

$$\bar{\tau} = \bar{\tau}_0 + d \left(\frac{A}{N} \pm \frac{1}{2} \right) \quad (1)$$

where $\bar{\tau}_0$ is the lowest value of exposure time at which the less frequency occurring symbol first appears, and d is the increment in successive exposure times. The negative sign is used when this symbol occurs at the highest exposure time, and the positive sign is used when it occurs at the lowest exposure time.

$$S = 1.620 \cdot d \left(\frac{NB - A^2}{N^2} + 0.029 \right) \quad \text{for } (NB - A^2)/N^2 > 0.3 \quad (2)$$

$$S_{\bar{\tau}} = \frac{6 S + d}{7\sqrt{N}} \quad (3)$$

Using these results it is possible to determine a 95% confidence interval, i.e. there is a 95% probability that $\bar{\tau}$ occurs between the two limits. The upper and lower limits of this interval are given by

$$\bar{\tau} \pm (t)(S_{\bar{\tau}}) \quad (4)$$

where t is taken from Student's t distribution for a probability of 95% and 6 degrees of freedom (N-1).

The table lists values of t (95% probability) against number of degrees of freedom.

Degrees of freedom	t
1	12.706
2	4.303
3	3.182
4	2.776
5	2.571
6	2.447
7	2.365
8	2.306
9	2.262
10	2.228

Using the typical Bruceton test results given in the first table of this section the calculated results would be

$$\bar{\tau} = 65 + 5 \left(\frac{10}{7} - \frac{1}{2} \right) = 69.64 \text{ ms} \quad (1)$$

$$S = 1.620 \cdot 5 \left(\frac{7.20 - 10^2}{7^2} + 0.029 \right) = 6.85 \text{ ms} \quad (2)$$

$$S\bar{\tau} = \frac{6.6 \cdot 85 + 5}{7\sqrt{7}} = 2.49 \text{ ms} \quad (3)$$

$$\text{Where } N = 7, \text{ there are six degrees of freedom,} \quad (4)$$

$$\text{therefore } t = 2.447$$

Therefore the 95% confidence limit = 2.447×2.49
= 6.09 ms

Thus, we may be 95% confident that $75.73 \geq \tau \geq 63.55$.

6 RESULTS

6.1 Propellant 'X' - Composite propellant

These tests were used to determine any batch to batch variation in 'X' propellant which was a composite material. Batches 16 and 18 were manufactured in the same way. Batches 21 and 24 had an additional treatment in acetone and liquid

nitrogen. It was necessary to determine if there were any variations, which were likely to occur in the rocket motor, in the ignition delay time. The results shown below summarise the results obtained under the various conditions indicated. All tests were at 125 psi (862 kN/m²).

Batch No. of 'X'	Incident flux constant at 2.27 MW/m ²				Incident flux constant at 1.52 MW/m ² zirconium carbide coated
	Zirconium carbide coated	Uncoated	Uncoated-acetone treated	Uncoated-Dipped in liquid nitrogen	
16	$\bar{\tau} = 25.21$ ms 24.67 ≤ $\bar{\tau}$ ≤ 25.75	$\bar{\tau} = 82.50$ ms 72.50 ≤ $\bar{\tau}$ ≤ 92.50	Previously cut samples $\bar{\tau} = 78.12$ ms 66.30 ≤ $\bar{\tau}$ ≤ 89.94 Not previously cut $\bar{\tau} = 80$ ms 71.75 ≤ $\bar{\tau}$ ≤ 88.25		
18	$\bar{\tau} = 24.93$ ms 22.25 ≤ $\bar{\tau}$ ≤ 27.61	$\bar{\tau} = 49.19$ ms 39.46 ≤ $\bar{\tau}$ ≤ 60.12 $\bar{\tau} = 68.21$ ms 61.07 ≤ $\bar{\tau}$ ≤ 73.75	Freshly cut samples $\bar{\tau} = 83.12$ ms 68.67 ≤ $\bar{\tau}$ ≤ 97.57 Previously cut samples $\bar{\tau} = 60.10$ ms	$\bar{\tau} = 83.93$ ms 78.11 ≤ $\bar{\tau}$ ≤ 89.75	
21	$\bar{\tau} = 24.33$ ms 20.06 ≤ $\bar{\tau}$ ≤ 28.60	$\bar{\tau} = 69.50$ ms 61.90 ≤ $\bar{\tau}$ ≤ 77.10			$\bar{\tau} = 54.94$ ms 39.37 ≤ $\bar{\tau}$ ≤ 69.91
24	$\bar{\tau} = 23.21$ ms 21.67 ≤ $\bar{\tau}$ ≤ 24.75	$\bar{\tau} = 50.33$ ms 47.01 ≤ $\bar{\tau}$ ≤ 53.65			$\bar{\tau} = 61.25$ ms 36.18 ≤ $\bar{\tau}$ ≤ 86.32

6.2 Double Base (Cordite) Propellant

50 psi (345 kN/m²)

Flux ₂ MW/m ²	Ignition delay ms	95% confidence limits	Ignition energy MJ/m ²
*4.38	21.86	20.16 ≤ $\bar{\tau}$ ≤ 23.56	0.0957 ± 0.0074
2.51	35.14	33.44 ≤ $\bar{\tau}$ ≤ 36.84	0.0882 ± 0.0043
1.98	38.75	31.90 ≤ $\bar{\tau}$ ≤ 45.60	0.0766 ± 0.0135
1.14	68.93	61.26 ≤ $\bar{\tau}$ ≤ 76.60	0.0787 ± 0.0088
0.75	102.50	84.30 ≤ $\bar{\tau}$ ≤ 120.70	0.0766 ± 0.0136
2.36	34.00	32.45 ≤ $\bar{\tau}$ ≤ 35.55	0.0802 ± 0.0037

* First five lines of data from A. Dunk⁸

100 psi (690 kN/m²)

Flux ₂ MW/m ²	Ignition delay ms	95% confidence limits	Ignition energy MJ/m ²
4.12	13.00	$10.38 \leq \tau \leq 15.62$	0.0536 ± 0.0108
2.27	27.93	$22.74 \leq \tau \leq 33.12$	0.0634 ± 0.0118
1.68	33.83	$29.43 \leq \tau \leq 38.23$	0.0568 ± 0.0074
0.98	65.36	$57.43 \leq \tau \leq 73.29$	0.0640 ± 0.0078

200 psi (1.38 MN/m²)

Flux ₂ MW/m ²	Ignition delay ms	95% confidence limits	Ignition energy MJ/m ²
3.79	9.17	$7.68 \leq \tau \leq 10.66$	0.0347 ± 0.0057
2.27	13.64	$12.96 \leq \tau \leq 14.32$	0.0310 ± 0.0015
1.68	24.10	$22.07 \leq \tau \leq 26.13$	0.0405 ± 0.0034
0.98	53.21	$47.93 \leq \tau \leq 58.49$	0.0521 ± 0.0052

The data is presented graphically in Figs 6 and 7.

7 DISCUSSION

7.1 'X' propellant

Regarding 'X' propellant, the purpose of the experiment was to discover if there was a significant batch to batch variation which would affect the ignition of the propellant in a rocket motor. As may be seen from the results, tests were carried out on the four batches at one particular flux level, and again on two of these batches at a different flux level.

Among the coated samples, there is no significant variation in ignition delay at either flux level. These results may be considered more useful than those where the samples are not coated with zirconium carbide, since the surfaces do not have a uniform reflectivity when uncoated. In column 2, the second result for X-18 should be regarded as the more reliable since the first one may be inaccurate due to the flux being low. The reason for this was that the lathe stanchion had loosened and moved in relation to the focus between the removal of the radiometer and the replacement of the "bomb".

Considering the third column where strips 16 and 18 are acetone treated (NB: strips 21 and 24 have already undergone this treatment in manufacture) the

distinction was made between samples which had previously been cut and those which were cut after being sprayed with acetone. This distinction was made after noting a variation in the results obtained with X-18. The variation was substantial on X-18, but negligible on X-16. It is, therefore, believed to be a strip to strip variation rather than a batch to batch one in this latter case. After acetone treatment there was a visible difference between the strips, before spraying the surfaces were shiny whereas after treatment they appeared dull.

Assuming the first results of the X-18, acetone treated, are characteristic of the batch, then the further treatment with liquid nitrogen may be seen to have no particular effect. It may appear from the results when noting the 95% confidence limits that the strips have a more uniform reflectivity, thereby reducing the variation due to this factor.

Thus, the conclusion drawn from the results obtained is that there is no significant variation between the batches. As stated previously, the most significant variation as far as the arc image furnace is concerned is the reflectivity of the propellant. As this is not important in the rocket motor due to the method of ignition it is not considered relevant. When the differences due to reflectivity are markedly reduced by coating then the ignition delay times of the various batches are very similar (see columns 1 and 5).

7.2 Double Base Propellant

The aim of this series of experiments using a double base propellant was to investigate the variation of ignition delay with pressure at various flux levels. Results at 50 psi were obtained by a former sandwich course student (Mr Dunk)⁸ and one of his tests was repeated whilst becoming familiar with the equipment.

It was found difficult to achieve consistent results at low flux level because the flux varied within about 40% of the mean value. Also, at this flux level ignition did not occur even after 200 ms (i.e. 57 revs). Any greater ignition delay would be virtually impossible to measure with this equipment.

Ignition of the propellant takes place near the surface of the propellant and since ignition occurs in an inert gas atmosphere in the arc image furnace and in a rocket motor, it is necessary to rely on both reactants (the fuel and the oxidiser) in the propellant to initiate ignition. The rate of decomposition of the propellant must be sufficient to supply both of these reactants in the required concentration which will allow ignition to occur under specific conditions of temperature and pressure. With increased temperature, the rate of decomposition is increased, resulting in reduced ignition delay times. A low pressure allows the gases to diffuse away from the propellant surface which results in a low concentration of the reactants

near the surface with a consequent low rate of reaction. Increasing the pressure causes the reactants to concentrate nearer to the surface of the propellant and this results in more rapid ignition in a zone near to the surface.

Theoretically¹⁰, at low pressures diffusion is a dominant factor and ignition energy here is a strong function of the pressure. When the pressure is raised this factor diminishes in importance and the thermal lag terms are dominant. Theory also predicts the minima in the curves with respect to heat flux which may be seen in Fig. 7. The energy required decreases at first with increasing flux as the contribution by conduction to the solid phase thermal wave thickness decreases. With the flux being further increased, this effect diminishes further and the dominant energy contribution is now during the chemical induction period. This energy term increases at high flux levels.

The results obtained may be compared with those obtained by Dunk⁸ using plastic propellant and rubbery propellant. The ignition delay with double base propellants is a function of pressure, especially at high flux levels, and the ignition energy passes through a minimum with respect to heat flux and this latter is more marked than with the composite propellants tested by Dunk.

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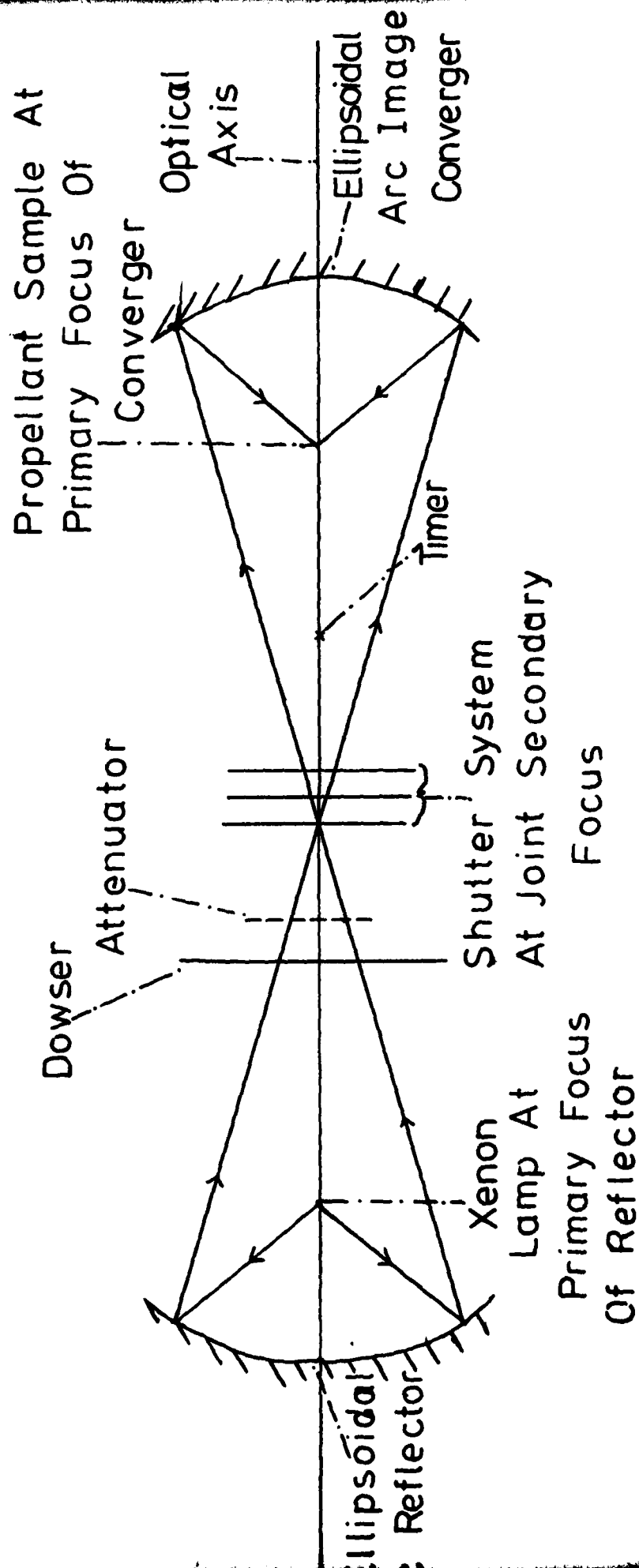
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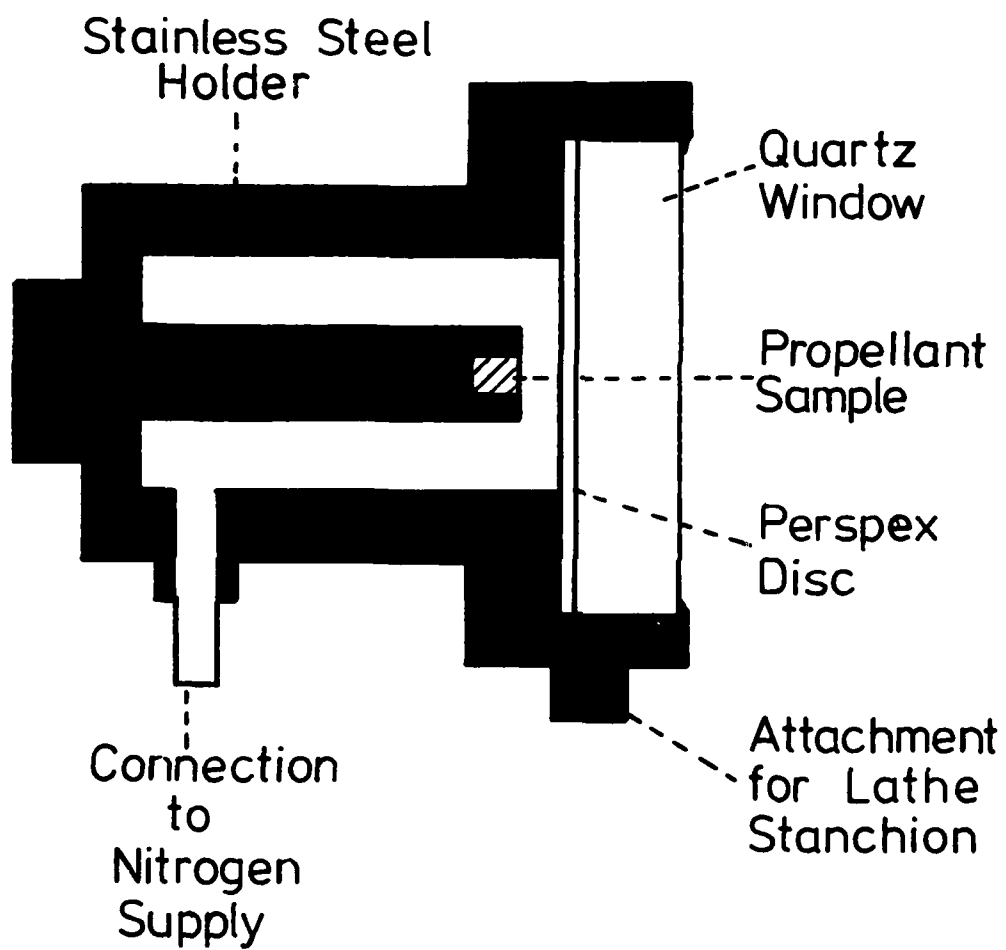
DIAGRAM OF AN ARC IMAGE FURNACE

Figure 1



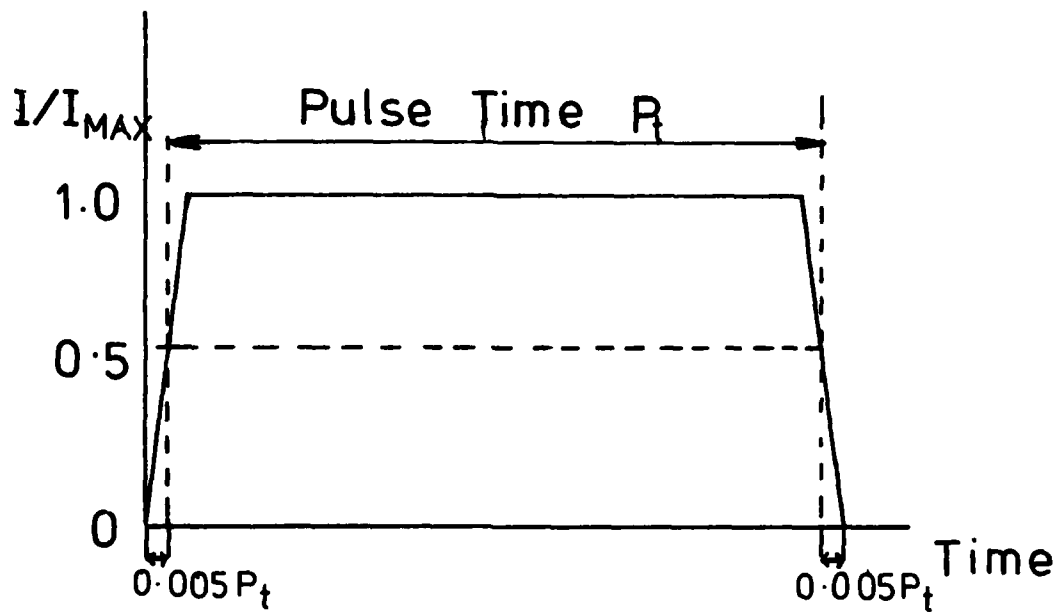
SAMPLE HOLDER or "BOMB"

Figure 2



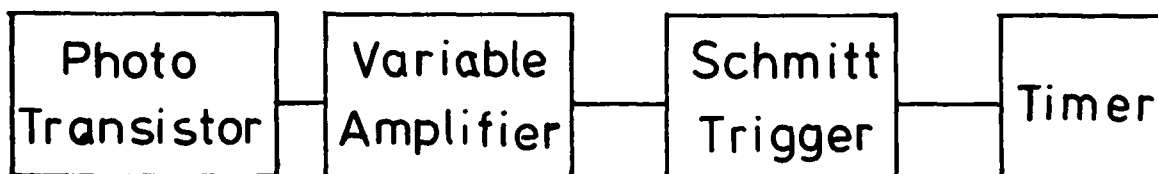
PULSE SHAPE

Figure 3



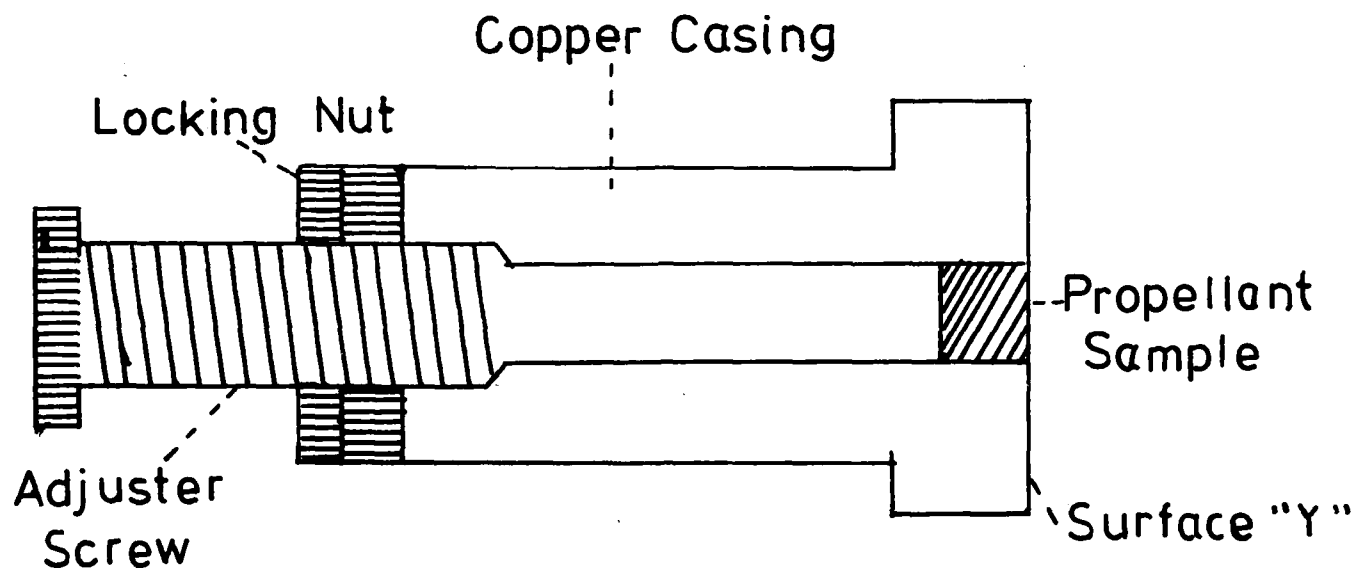
SCHEMATIC DIAGRAM OF THE TIMER CIRCUIT

Figure 4

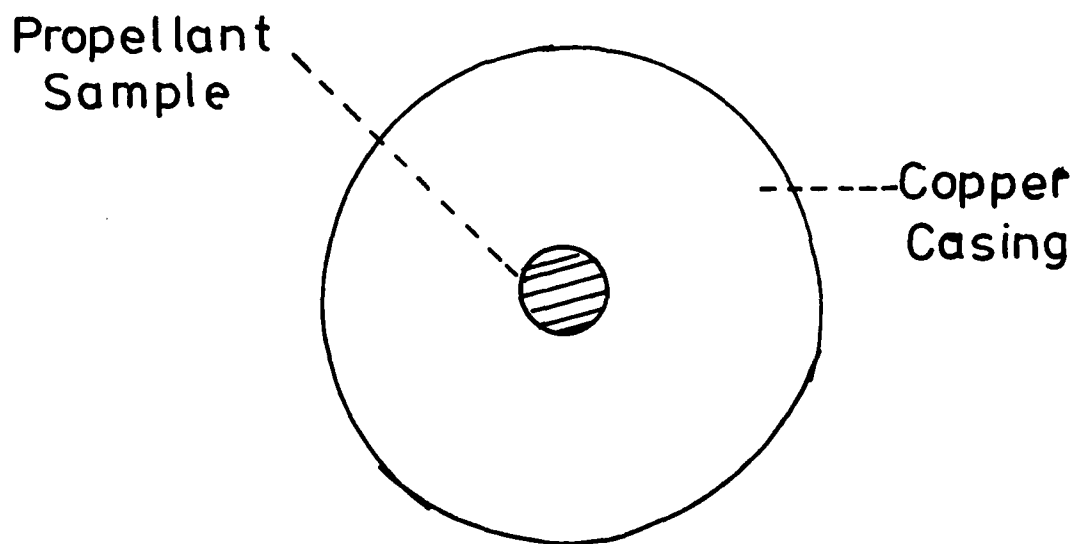


LONGITUDINAL SECTION OF MICROTOME

Figure 5



VIEW OF SURFACE "Y"



Variation of Ignition Delay Time τ

With Absorbed Heat Flux At

50, 100, 200 p.s.i.

Figure 6

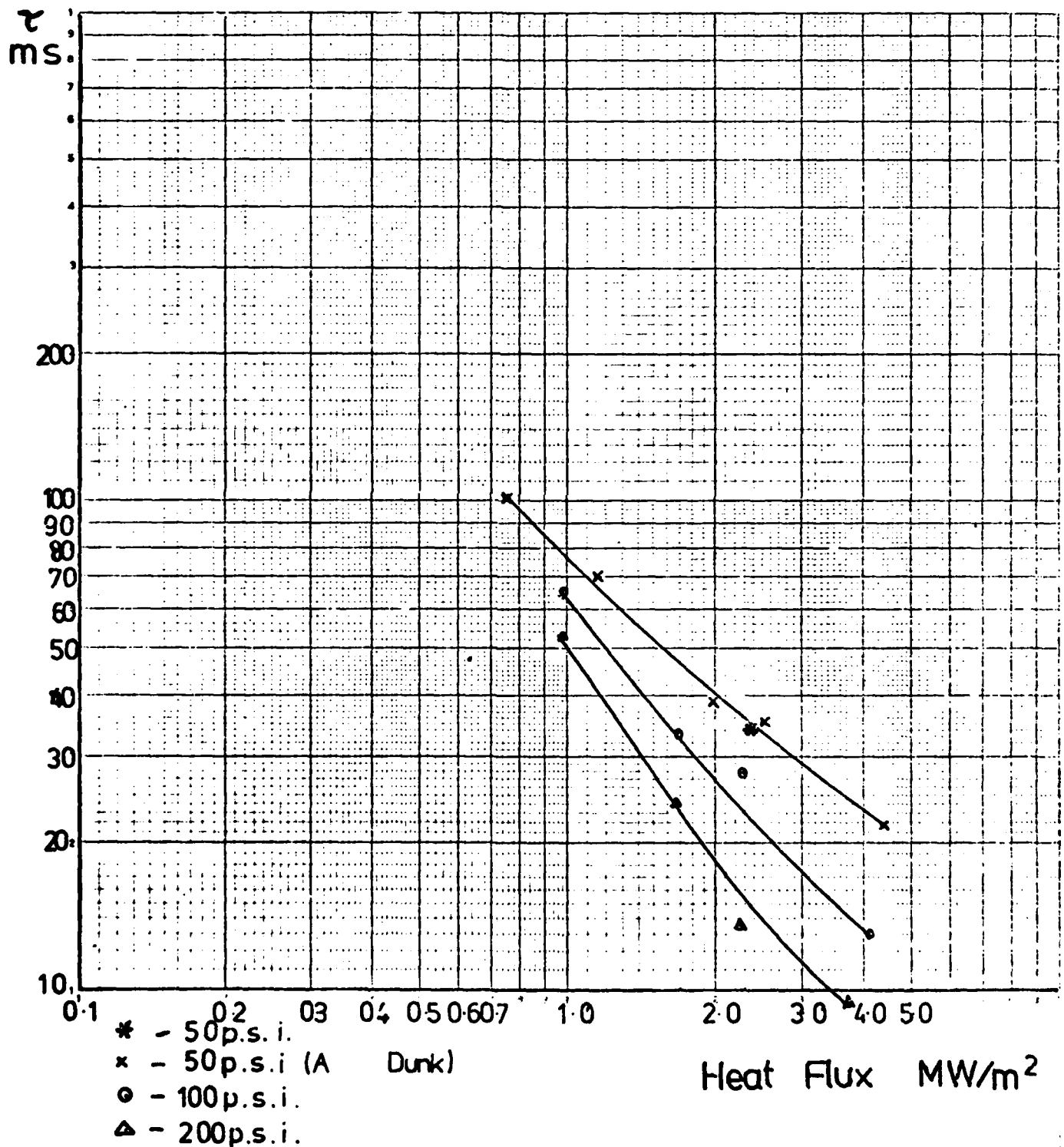
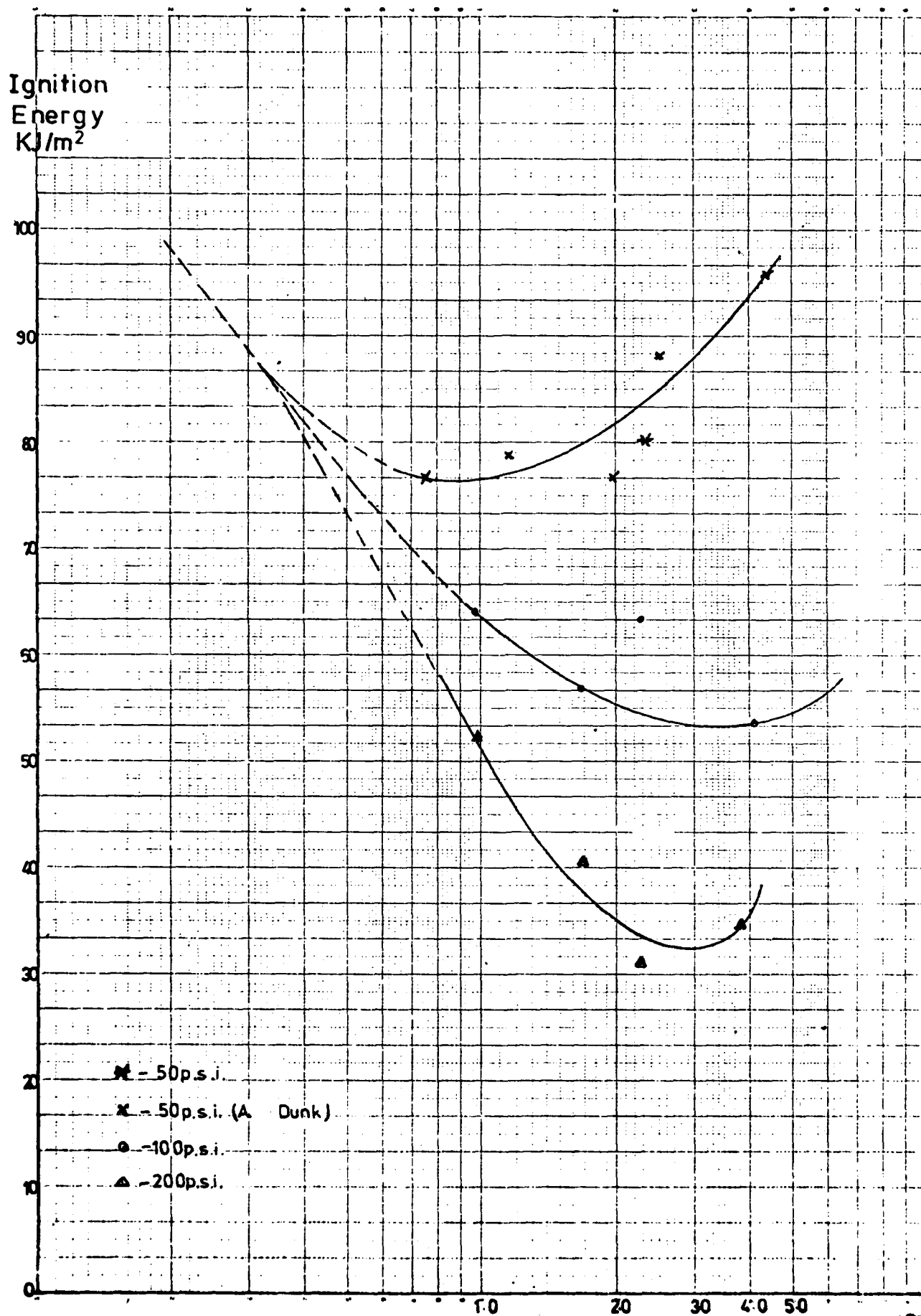


Figure 7

Variation Of Ignition Energy With Heat Flux At 50,100,200p.s.i.



DOCUMENT CONTROL SHEET

(Notes on completion overleaf)

Overall security classification of sheet Unlimited

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R), (C) or (S)).

1. DRIC Reference (if known)	2. Originator's Reference Memorandum 111	3. Agency Reference	4. Report Security Classification Unlimited
5. Originator's Code (if known) 7281500 M	6. Originator (Corporate Author) Name and Location Propellants, Explosives & Rocket Motor Establishment Westcott, Aylesbury, Bucks		
5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and Location		
7. Title The use of an arc image furnace for solid propellant ignition studies			
7a. Title in Foreign Language (in the case of translations)			
7b. Presented at (for conference papers). Title, place and date of conference			
8. Author 1. Surname, initials Dawes, J.B.	9a. Author 2	9b. Authors 3, 4...	10. Date pp ref 5.1980 19 10
11. Contract Number	12. Period	13. Project	14. Other References
15. Distribution statement			
Descriptors (or keywords) Solid rocket propellants; Ignition delay; Heat flux; Pressure; Electric arc furnaces. <div style="text-align: right;">continue on separate piece of paper if necessary</div>			
Abstract An arc image furnace has been used to test the ignition delay of rocket propellant under varying conditions of heat flux and pressure.			